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AN AUTOMATIC MICROIMAGE FILE

searches film record and makes photographic print

A MICROIMAGE data storage and retrieval device recently developed at the National Bureau of Standards provides rapid access to any one of 10,000 information-containing frames recorded in miniature on a 10-in.- square sheet of microfilm. The instrument operates on a continuous basis; it automatically searches the microfilm and photographically prints out one frame every 2 seconds. Designed and built by M. L. Kuder of the electronic instrumentation laboratory, the device is intended for use in other Government agencies.

The machine is particularly applicable where large volumes of data must be assembled in a predetermined sequence from a master random file. Information may be in the form of pictures, drawings, fingerprints, sets of numbers, letters, or other symbols, or even single stages of electronic circuit diagrams. Quantity and kind of data is limited only by the size of the individual frame ($\frac{1}{10}$-in. square) and the photographic resolution of the film emulsion. Although the basic storage capacity of the machine is for a 10,000 frame matrix, the matrix can be interchanged with others.

Input to the machine is from a perforated teletype tape containing the coded locations of the desired frames in the order in which they are to be printed out. The assembled data produced by the machine comes out on a 10-in. wide strip of photosensitive paper of any required length. Individual frames are enlarged to $\frac{1}{2}$-in. squares. Commercial automatic developing equipment processes the photographic paper.

The instrument is essentially a combination of digital computer electronic circuitry and a pair of precision servomechanisms that search X and Y axes of the matrix. The location of the desired frame is fed into a 20-bit (binary digit) register from the teletype tape. The register consists of a capacitor memory and coincidence identification circuitry. The first 10 bits recorded in the register control the Y position selection while the second 10 bits control the X position.

The matrix is supported on a drum 10 in. in diameter and is fastened at one edge with dowel pins to insure its accurate location on the drum. The drum is servo-controlled in both linear and rotary axes of motion, corresponding to the X and Y axes of the matrix. The servos that shift the matrix to the chosen coordinates are mechanically coupled with precision gearing to two code commutators.

The code commutators, one associated with each axis, control the coordinate positions to which the matrix is located. These commutators are photoetched with one hundred 10-bit numbers corresponding to the standard teletype binary bit code. The two particular positions on the commutators are selected by a serial mechanical search with contacting brushes until a code combination is found that matches the binary bits re-

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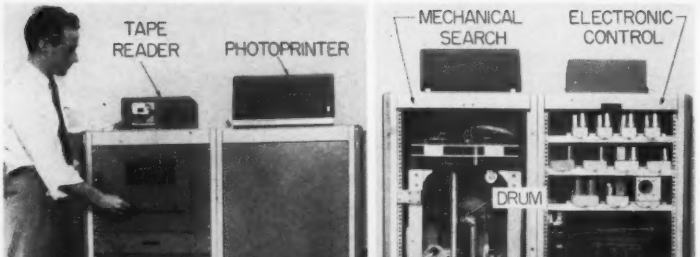


This microimage data storage and retrieval device provides rapid access to any one of 10,000 information-containing frames recorded in miniature on a 10-in.-square sheet of microfilm. The first cabinet, with teletype tape reader on top, contains the electronic control circuity. The second cabinet encloses the mechanical equipment for searching the microfilm; on top is unit for photographic paper on which information is printed out. Right photo shows rear view of microimage file. Film is fastened to drum in center of left cabinet.

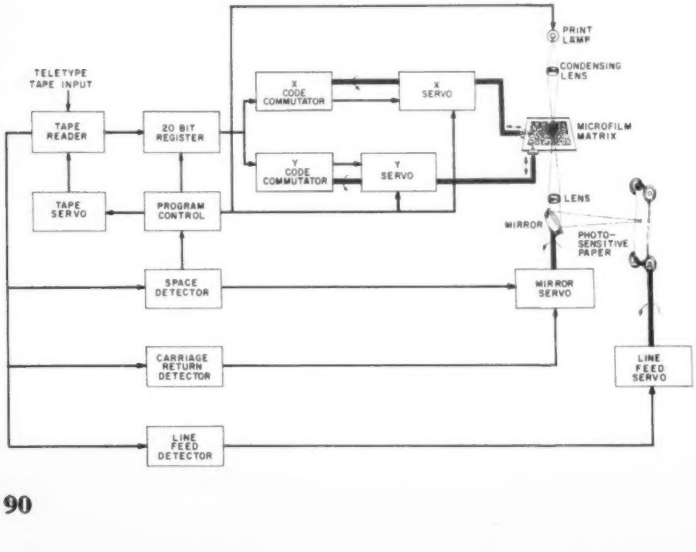
corded in the 20-bit register. Magnetic clutches and brakes provide rapid starting and stopping of the drum with uniform overtravel in locating every position on the matrix. A single induction motor supplies all motive power to the machine.

At the beginning of the cycle of operation, a teletype tape reader reads a 4-decimal-digit number into the 20-bit register in terms of a binary-digit code. A space symbol is customarily inserted in the teletype tape following each 4-digit number. On detecting this space symbol, the machine's program control stops the tape reader, engages the magnetic clutches on the X and Y servos, and looks for the compatible code on the two coordinate axes. When the compatible code is found, the clutches disengage and magnetic brakes stop the drum. A print lamp is briefly turned on to make a photographic exposure of the selected microfilm frame on the photosensitive paper. When the exposure is completed, the teletype tape advances to the next instruction, the drum returns to its zero position, and the machine proceeds with the next search cycle.

Fifteen successive frames are printed in a row across the 10-in. width of the print paper by means of a step positioning mirror. This mirror performs a function similar to the character spacing on a typewriter: it automatically advances the image one space on the photographic paper for each printout. Upon completion of a line, a line-feed servo advances the paper a fixed amount.

The instrument recognizes two other symbols, the "carriage return" and the "line feed." These symbols instruct the machine to return the step positioning mirror to its zero position, and to advance the paper one line. Whenever these functions are desired, they can be inserted into the teletype tape.

Although the machine was primarily designed as an outscriber for obtaining programed printing from a large file of negatives, it can temporarily be set up as an inscriber to prepare its own matrices of 10,000 frames each. Using the same machine to prepare a matrix insures that each frame will be accurately located whenever it is subsequently used.



Block diagram of automatic microimage file system. Instrument operates on a continuous basis, searching for and printing out one frame every 2 sec.

SHOCK LOADING OF TEXTILE YARNS

studies of tensile impact properties of materials

THE ABILITY of textile yarns to withstand high-speed impact stresses, or shock loading, is becoming increasingly important to modern industry and to national defense. Extremely high rates of strain are experienced by airplane tire cords during landing, by seat belts and safety lines when accidents occur, and by the fabric, shroud lines, and webbing during the opening of a parachute. In high-speed industrial sewing the thread is subjected to impact velocities ranging from 1 to 10 meters per second as often as 5,000 times per minute. This results in high-frequency cyclic accelerations of the thread, which may equal several million centimeters per second per second. Similar conditions may be attained in high-speed processing of fibers, such as carding and combing or the weaving and knitting of yarns into fabrics.

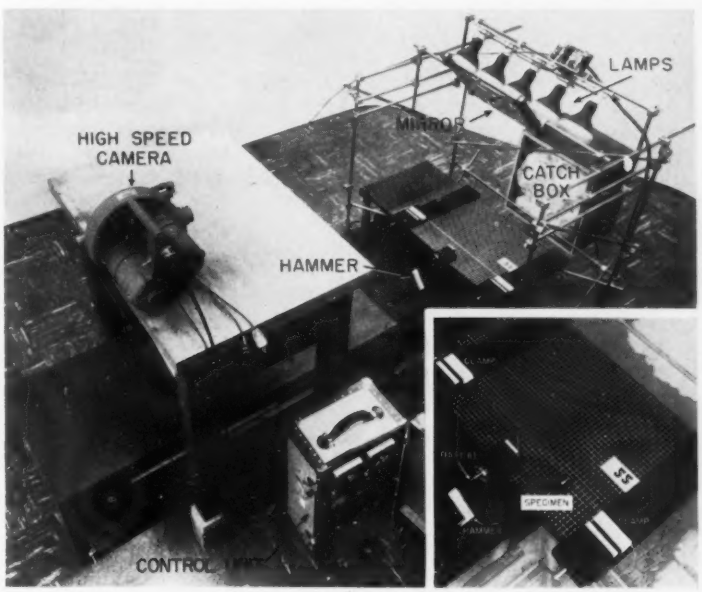
To provide design data for these various applications, the Bureau has been making an extensive study [1] of the behavior of textile yarns under very high-speed impact. The study seeks to determine the effects of high rates of strain on textile materials and to relate these results to the molecular structure of the fibers and the geometry of the yarns and fabrics. In this way, it is hoped, information leading to the development of fibers having improved impact properties will be obtained. The program, directed by H. F. Schiefer of the NBS staff, has been partially supported by the U. S. Army Quartermaster Research and Development Command.

Important criteria in judging the ability of textile yarns to withstand shock loading include the magnitude and propagation velocity of the stresses and strains developed in the material, the energy absorbed and recoverable, and the energy to rupture. Two testing machines have been developed for studying these characteristics at rates of deformation from about 1,000 to 10,000 percent per second. One of these employs a pair of rapidly moving hammers to subject yarn specimens to longitudinal impact at speeds up to 80 m/sec. The other incorporates a spring-driven impeller and is used to study the effect of transverse impact with a projectile flying at speeds up to 65 m/sec.

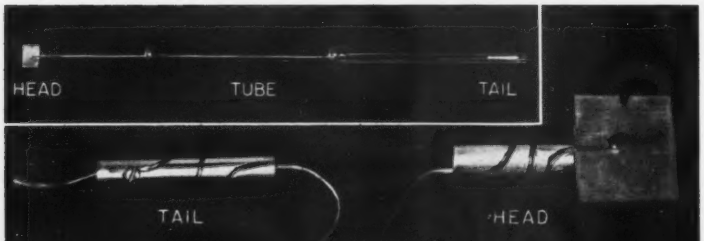
In the longitudinal tests, the ends of a 2-ft yarn specimen are attached to head and tail masses, and the specimen is supported fully extended between these masses in a metal tube which is mounted on the impact machine. High-speed impact occurs when a pair of hammers attached to the rim of a rapidly rotating wheel strikes the head mass.

The hammers are attached on each side of the rotating wheel so that they pass on either side of the head mass while the wheel is being brought up to speed. When impact is desired, the tube holding the head mass is rapidly rotated through 90° by means of a spring-loaded cam actuated by a triggering circuit. This causes projections on the head mass to lie directly in the path of the hammers. Thus, when the hammers strike the head mass, the tensile stress on the specimen is applied very rapidly.

After impact the head mass, specimen, and tail mass



Experimental setup devised for studying high-speed transverse impact in textile yarns. The yarn specimen is clamped above a grid system on a rigid table (inset). The hammer impels a projectile toward the center of the specimen and into a catch box. During and after impact a high-speed motion picture camera photographs the specimen and underlying grid system as reflected in the mirror and illuminated by flood lamps. Control unit is for starting camera and putting timing pips on the photographic record.



Equipment developed for study of high-speed longitudinal impact in textile yarns. The yarn specimen under study is first attached to head and tail masses and then suspended, with masses attached, in metal tube (inset) which is supported above a rotating wheel in the impact machine.

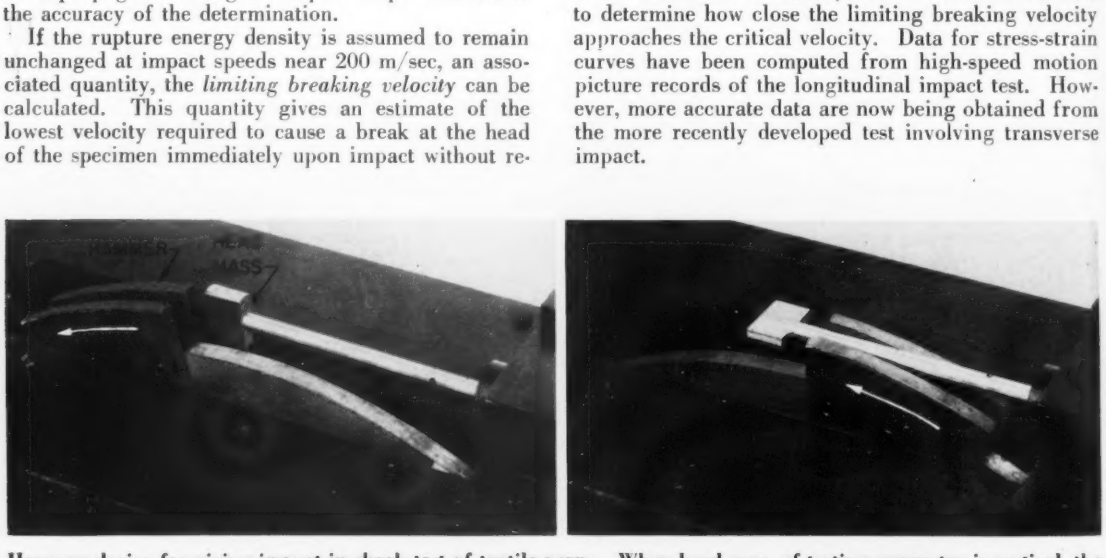
fly off in the direction of impact and are collected in a catch box for subsequent examination. If the inertial force exerted by the tail mass is sufficiently large, the specimen will rupture. The object of the test is to determine the lowest impact velocity for a given specimen and given tail mass at which the specimen will be ruptured. Data from tests made on specimens of various lengths with various tail masses attached are used to compute the *rupture energy density* for the specimen material.

Rupture energy density is a quantity that is characteristic of the material tested and is useful in engineering design. It gives the amount of energy required to break unit mass of textile yarn. This quantity can be measured accurately at impact speeds up to 50 m/sec. However, at higher speeds the effect of strain wave propagation along the impacted specimen limits the accuracy of the determination.

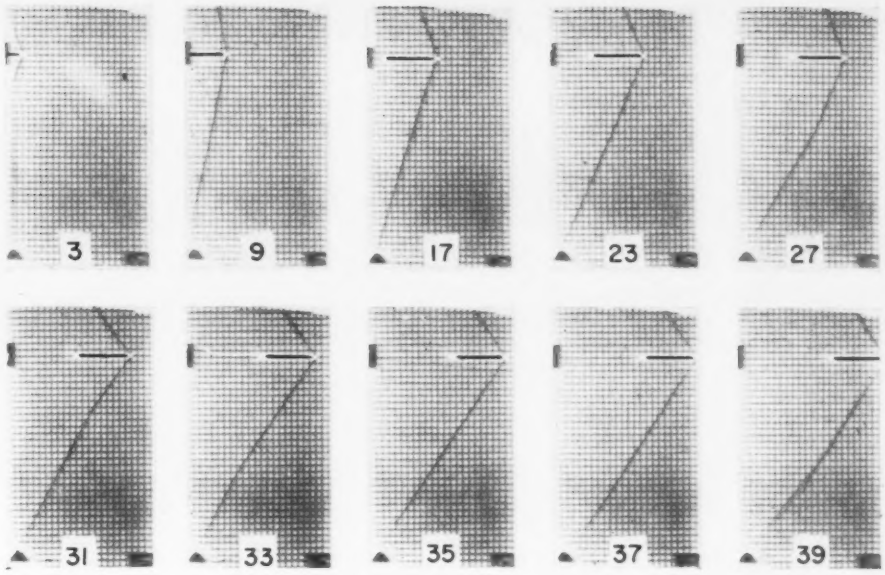
If the rupture energy density is assumed to remain unchanged at impact speeds near 200 m/sec, an associated quantity, the *limiting breaking velocity* can be calculated. This quantity gives an estimate of the lowest velocity required to cause a break at the head of the specimen immediately upon impact without regard to the specimen length or tail mass used. The limiting breaking velocity of high-tenacity nylon is 240 m/sec.

The actual velocity that will just produce an immediate impact break is called the *critical velocity*. It is usually slightly less than the calculated limiting breaking velocity and depends on the shape of the stress-strain curve for the material. The limiting breaking velocity depends only on the area under the stress-strain curve.

With present equipment it is not possible to measure directly the critical velocities of all textile materials of interest. However, the data on rupture energy density obtained in the longitudinal impact test can be used to compute the limiting breaking velocity as an estimate of the critical velocity. Then, if high-speed stress-strain curves are available, these curves can be used to determine how close the limiting breaking velocity approaches the critical velocity. Data for stress-strain curves have been computed from high-speed motion picture records of the longitudinal impact test. However, more accurate data are now being obtained from the more recently developed test involving transverse impact.



Hammer device for giving impact in shock test of textile yarns. When head mass of testing apparatus is vertical, the two hammers on each side of rotating wheel pass on either side and no impact occurs. When impact is desired, the head mass is rotated through 90° so that the hammers strike the head mass.



Film frames showing motion of projectile and configurations of yarn specimen during a transverse-impact test. Impact occurred just prior to frame 3. Strand-by-strand breakage began at frame 37. Camera speed was 6,984 frames per second.

In the transverse impact test, the yarn specimen is clamped to a rigid massive table on which a coordinate grid system is inscribed. A freely flying projectile, impelled by a rapidly revolving spring-driven hammer, makes transverse impact with the yarn specimen at its center.

A plane mirror reflects images of the specimen and grid system so that they can be photographed with a high-speed camera during and after impact. The camera used can make up to 15,000 pictures per second. Measurements on the photographic record provide data from which the stress-strain curve for the yarn specimen, over a period of about 1 millisecond, may be calculated.

When the yarn specimen is struck transversely by the projectile, a longitudinal strain wave is propagated along the yarn, outward in each direction from the point of impact. In the region between these two wave fronts the material of the yarn is set into motion toward the point of impact. This inward flowing material forms itself into a tent-shaped wave with the impacting projectile at the vertex. The material forming the "tent" moves in the direction of the projectile with the velocity of the projectile. The base of the tent propagates outward as a transverse wave with a velocity that depends upon the tension in the specimen. This transverse wave travels back and forth along the specimen, undergoing reflection alternately at the clamps and at the projectile. At each reflection the configuration of the specimen changes markedly.

To obtain the stress-strain curve, the specimen length is measured in each picture of the photographic record. The strain, or ratio of change in length to the original length, is thus obtained as a function of time. The position of the transverse wave front is also measured in each picture and the velocity of the transverse wave found as a function of time. A simple mathematical relationship then gives the tensile stress in the specimen for each transverse wave velocity. The stress-strain curve is plotted from these data for stress and strain as a function of time.

Both the longitudinal and transverse machines are now being employed to study the impact properties of representative textile yarns. Also under study is the influence of molecular structure, ambient temperature, and yarn geometry on the impact properties of textile cords and braided structures. The results of this work should not only provide valuable design data but should also increase understanding of the basic impact properties of materials.

[1] *For further details, see* Stress-strain relationships in yarns subjected to rapid impact loading: 1. Equipment, testing procedure, and typical results, *by W. K. Stone, H. F. Schiefer, and G. C. Fox, J. Research NBS* **54**, *269 (1955) RP2589; also in Textile Research J.* **25**, *520 (1955).*

Stress-strain relationships in yarns subjected to rapid impact loading: 2. Breaking velocities, strain energies, and theory neglecting wave propagation, *by F. L. McCrackin, H. F. Schiefer, J. C. Smith, and W. K. Stone, J. Research NBS* **54**, *277, (1955) RP2590; also in Textile Research J.* **25**, *529 (1955).*

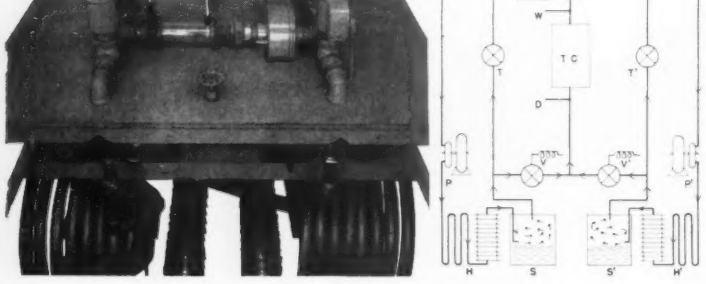
Stress-strain relationships in yarns subjected to rapid impact loadings: 3. Effect of wave propagation, *by J. C. Smith, F. L. McCrackin, and H. F. Schiefer, J. Research NBS* **55**, *19, (1955) RP2601; also in Textile Research J.* **25**, *701 (1955).*

Stress-strain relationships in yarns subjected to rapid impact loading: 4. Transverse impact tests, *by J. C. Smith, F. L. McCrackin, H. F. Schiefer, W. K. Stone, and K. M. Towne, J. Research NBS and Textile Research J. (in press).*

Humidity Step-Function Generator

A SIMPLE apparatus for producing sudden changes in relative humidity at room temperature has been designed and constructed by the Bureau.[1] The equipment was developed by S. Hasegawa, S. B. Garfinkel, and A. Wexler of the mechanical instruments laboratory as part of a program sponsored by the Navy Bureau of Aeronautics.

Growing out of the need for simpler and more convenient methods for testing meteorological hygrometer elements, the device is used to measure the speed with which such elements respond when the humidity changes suddenly from one fixed value to another. A prompt response is important, for example, in hygrometers attached to balloons that rise swiftly through changing air strata; a lag in the response of the hygrometer seriously reduces the accuracy of its continuously recorded measurements. Another application to which the humidity-change equipment can be adapted is the accelerated aging of hygrometer elements by rapid humidity cycling.



Apparatus for producing sudden changes in relative humidity. Two independent humidity systems can be connected alternately to test chamber (top center). Large copper coils and finned radiator are heat exchangers that keep air within apparatus at room temperature. Wet and dry bulb thermometers extend above test chamber with air velocity meter at upper right. Diagram shows humidity systems connected to test chamber, TC. Pump, P or P′, circulates air through heat exchanger, H or H′, to chamber containing salt solution, S or S′. Each system can be connected to test chamber by valves, V or V′. Bypass valve, T or T′, controls flow of air through test chamber which is measured by flowmeter, F, with indicator, I. Wet and dry bulb thermometers, W and D, check relative humidity in test chamber.

The apparatus consists basically of two closed and independent humidity systems, either of which may be connected to a test chamber. By means of solenoid-controlled valves, the chamber can be switched rapidly from one humidity system to the other. Air in each system is kept moving by an oil-free impeller-type pump, and for an air flow of 200 liters per minute, the time required for the change from one humidity to the other is about 0.05 sec or less.

The value of the relative humidity in each system is controlled by a saturated salt solution. Held in a cylindrical glass chamber, 8 in. in diameter and 8 in. high, the solution is made up as a slushy mixture with distilled water and chemically pure salt. It is well known that when a container is sealed and air is circulated within it to obtain equilibrium conditions, the space above the solution assumes a constant relative humidity. The precise value of this humidity depends on the salt used and also, in general, on the temperature.[2] For the purposes of the present apparatus, however, it is possible to choose salts that produce the required relative humidity and which have a small or negligible temperature coefficient at room temperature.

In each humidity system, the air is driven by a pump first through a heat exchanger, which brings the air within the system to room temperature. It is then conducted to the salt solution chamber where, by an arrangement of nozzles and baffles, it is brought in intimate contact with the solution. From the salt solution chamber, the air may take one or both of two paths. It may flow through a bypass, and return directly to the pump, or when the proper valves are open, it may pass through the test chamber before returning to the pump. When the valves are set so that the system is connected to the test chamber, another valve in the bypass may be adjusted until a flowmeter indicates the desired flow rate through the test chamber.

During the time that one of the systems is connected to the test chamber, the air in the other system continues to be circulated by its pump. Then, when the electrically controlled valves switch the chamber from one system to the other, the old air is quickly replaced by new. With an air current of 200 liters per minute, it takes 0.01 sec for a single change of air through the test chamber. Because of residual air in the chamber and dead spaces in the plumbing, about 0.03 to 0.05 sec is needed to establish the new relative humidity.

To provide for different air speed requirements and for the different sizes of hygrometers tested, several interchangeable test chambers are used. In one of these, air speeds up to 570 ft/min have been attained. The air speed meter is of the glass-wool linear type.

So far the apparatus has been used principally for studies of an NBS-designed electric hygrometer element.[3] In these studies, a check was made on the relative humidity in the test chamber by means of wet and dry bulb thermometers. It was found that the relative humidity is held constant within about 2 percent.

[1] *For further technical details, see* Simple humidity lag apparatus, *by S. Hasegawa, S. B. Garfinkel, and A. Wexler, Rev. Sci. Instr.* **26,** *1196 (1955).*

[2] Relative humidity-temperature relationships of some saturated salt solutions in the temperature range 0° to 50° C, *by A. Wexler and S. Hasegawa, J. Research NBS* **53,** *19 (1954) RP2512.*

[3] A rapid-response hygrometer, *NBS Tech. News Bull.* **38,** *86 (1954)*; A fast responding electric hygrometer, *by A. Wexler, S. B. Garfinkel, F. E. Jones, S. Hasegawa, and A. Krinsky, J. Research NBS* **55,** *71 (1955) RP2606.*

NBS Metallurgical Conference

THE BUREAU was host to about 130 representatives of Government and industry at its annual Metallurgical Conference on May 14. Five technical papers were presented, describing work now in progress in the laboratories of the Bureau's Metallurgy Division.

The Metallurgical Conference has been an annual event at NBS since 1913, with the exception of the war years. It has proved an effective means for keeping American science and industry informed regarding the Bureau's program in metallurgy. This program is concerned with the structure and behavior of metals and alloys as affected by treatment, fabrication, and conditions of service. In general, it seeks a better understanding of the properties of metals in order that new or improved metals and alloys may be developed to give better performance or to meet new applications.

The Conference was opened by Dr. A. V. Astin, Director of the Bureau, and Dr. J. I. Hoffman, Chief of the Metallurgy Division. The technical papers followed, after which the guests were free to visit the various laboratories of the Division.

In the first of the technical papers, Jerome Kruger outlined plans for a new fundamental investigation of corrosion and gave some preliminary results that have already been obtained. This investigation was designed to study the nature, structure, and rate of growth of oxide films which form on single crystals of copper when they are immersed in pure water containing various amounts of oxygen.

Fatigue crack initiation in aluminum alloys 1100 and 5052 was discussed by J. G. Weinberg. These cracks appear to originate in pre-existing slip bands on planes parallel to the octahedral planes (111). There was no evidence that grain boundaries play any part in initiating cracks. Under torsion loading, the resolved shear stress was the only factor that determined which crystals developed fatigue cracks. However, in bending, cracks always developed in crystals located at the corners of the cross section even though crystals farther away from the corner may have had higher resolved shear stresses.

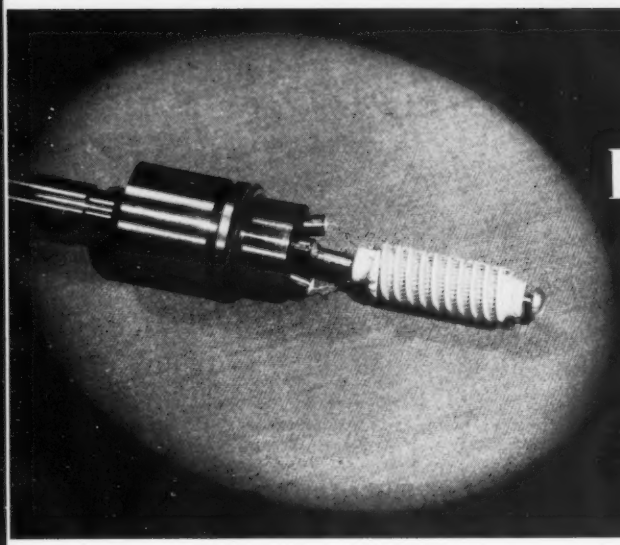
To study the early stages of crack initiation in detail, a small torsion testing machine was designed to fit the stage of a metallurgical microscope. Highly magnified time-lapse motion pictures were then made of the surface of a specimen of 5052 aluminum alloy undergoing the torsion test. These pictures revealed the extrusion of a light friable material of unknown composition from cracks just after their initiation. This material is believed to be produced by the rubbing action of the surfaces of the cracks. The film excited much interest among the participants in the conference.

Newly designed equipment for making electrical resistance measurements was described by G. A. Moore. This equipment was developed especially for applicaton to alloy diagram studies and to the standard metals field. Specimens may be carried through a precise temperature program while in vacuum, or protective atmosphere and their resistances recorded as a function of temperature. Sensitivities of about 1 part in 10 thousand are obtained and rapid transient effects are observed. The effect of heating and cooling rates on passing through a solid solution limit was shown together with new data on the resistance of high-purity iron.

C. J. Bechtoldt discussed some recent phase diagram studies of the quaternary system Cr-Fe-Mo-Ni for alloys containing 70 percent of iron. The composition of the fields of stability of phases determined at several temperatures between 1,500° and 2,200° F was discussed, and the results were summarized in ternary diagrams in which the different phase fields were distinguished by different colors. Five brittle phases—σ, χ, ϵ, η, and ρ—as well as σ-iron and γ-iron were identified. Three of the brittle phases—σ, χ, and ϵ—are well known and have been described previously, but the η-phase having the composition Fe_2Mo has not been identified before in phase diagrams of the Fe-Mo, Cr-Fe-Mo, or Fe-Mo-Ni systems, and the ρ-phase has not been reported previously. The latter phase in the quaternary alloys had a composition of approximately 4 percent of chromium, 52 percent of iron, and 44 percent of molybdenum at 1,800° F.

M. R. Meyerson described a method for obtaining any desired uniform slack-quenched structure below the notch of a standard Charpy V-notch impact specimen. This method consists of end quenching by immersing the specimen blank so as to obtain the desired rate of cooling at the location of the notch. It is economical in material consumed and in machining time and can be used on steel with low hardenability.

Several modifications of 8140 steel were slack quenched by this method so as to obtain areas of equal hardness with equal cooling rates in pairs of the different steels. The impact properties of the steels were determined over a range of temperatures both in the slack-quenched and in the slack-quenched and tempered conditions. These data also were compared with the values obtained with these steels fully hardened and tempered to the same hardness levels. The effect of slack quenching upon the impact properties varies considerably depending upon the composition and hardness of the slack-quenched structure.

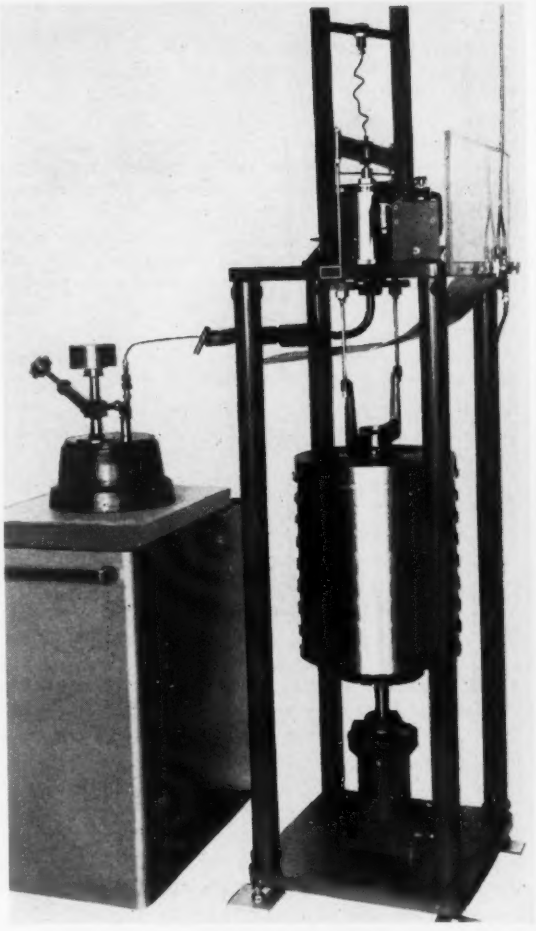


High-Pressure Standards

TO KEEP PACE with the increasing use of high pressures in industry and scientific research, the National Bureau of Standards has undertaken development of instruments and standards that will permit more accurate measurement of pressures up to 200,000 pounds per square inch (psi) and higher. Partial support for the program is provided by Watertown Arsenal of the Army Ordnance Corps and the Interior Ballistics Laboratory at Aberdeen Proving Ground. The work is being carried on by D. P. Johnson, H. A. Bowman, J. L. Cross, and J. D. Hill of the pressure measurements laboratory, under the general direction of E. C. Lloyd.

Up to the present, nearly all measurements in this field have been referred to fixed pressure points, associated with phase transitions in water and mercury, as determined by P. W. Bridgman about 45 years ago. Yet the need for accurate high-pressure measurements and additional determinations of fixed pressure points continues to grow as higher and higher pressures come into use.

A complete list of the applications of high pressure and its measurement would cover a range of processes from the production of artificial diamonds to the manufacture of ordnance; and it would include the extrusion of metals and plastics, the operation of oil wells, and a wide variety of operations in chemical technology. Geophysicists have been making pressure



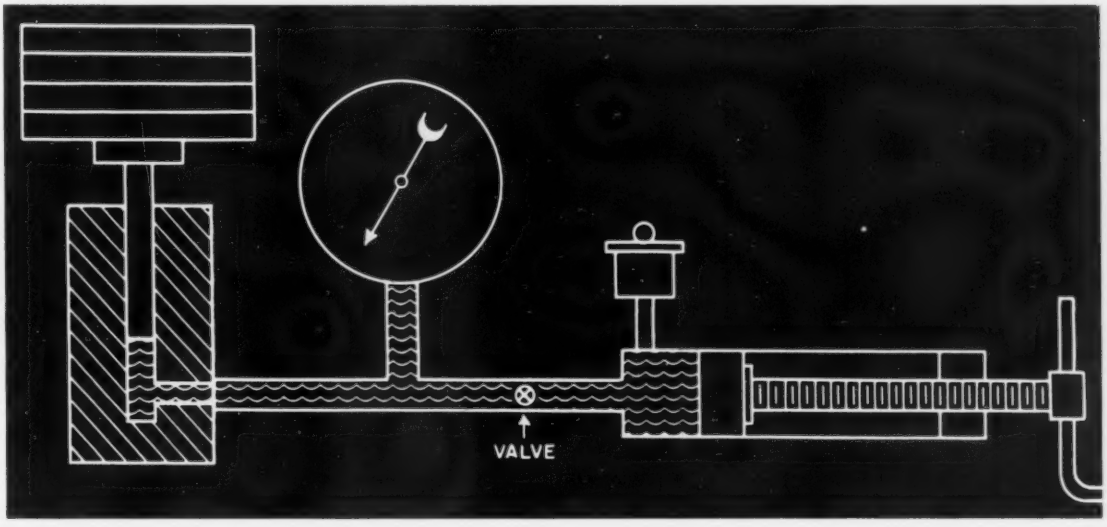
Above: **Insulating plug used as holder for a pressure-sensitive resistance coil. Used for working measurements of pressures up to 200,000 psi, the plug is mounted in a high-pressure vessel with the spiral-wound manganin coil projecting inward. Though of the same size as conventional single-lead plugs, this brings four leads out of the pressure vessel, two from each end of the coil. Resistance of the insulating bushing is about 1,000 megohms per lead.**

measurements in this range for many years. A newer application is to the study of the high pressures generated by nuclear explosions.

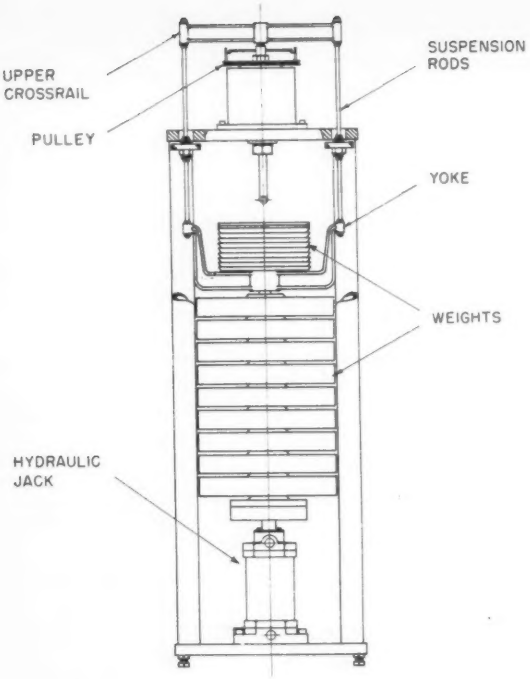
Pressures of 150,000 psi and above, for example, are used in the field of ordnance, both in laboratory studies and in such large-scale operations as the autofrettage, or pressure seasoning, of cannon bores. Perhaps the best illustrations of the higher pressures now being extensively used are provided by chemical technology, especially in connection with catalytic polymerization and hydrogenation. The commercial production of such substances as polyethylene makes use of pressures in the range of 15,000 to 50,000 psi; and industrial laboratory studies of new polymeric substances are moving into the range from 100,000 to 200,000 psi. In the hydrogenation of coal, pressures as high as 100,000 psi are currently being used to produce a variety of chemical products such as benzene, toluene, aniline, cresols, and indole. High pressures are also being used in other NBS research, e. g.: 140,000 psi in studies of pressure-volume-temperature relations in leather, and pressures higher than 200,000 psi in studies of crystal-forming reactions.

Experience has shown that pressure-measuring or -controlling instruments should be calibrated with an accuracy better by a factor of about three than the accuracy within which the instrument is intended to work. This places severe requirements on the accuracy needed in the fundamental pressure standards in order that industry may manufacture and maintain devices for process control at an accuracy within one percent. The process-control instrumentation should then have better than 0.3 percent accuracy, the bench standards for calibrating these should be accurate within 0.1 percent, and the plant master standard better than 0.03 percent. The Bureau, serving as monitor of the master standards, should then have fundamental standards within 0.01 percent accuracy. The work of research laboratories, often requiring data accurate to 0.03 percent or better, makes even more stringent demands, requiring primary standards of accuracy better than 0.01 percent. Actually, these estimates are minimal, and accuracies considerably higher than the 0.01 percent now attainable with the Bureau's piston gages would be very desirable.

The Bureau's program on high-pressure standards and measuring techniques is proceeding along several different but related lines of approach. One principal effort is on the development of piston gages for absolute measurement of pressure up to 200,000 psi. Other objectives of the program are (1) determination of a series of fixed points on the pressure scale, (2) establishment of standards for calibration of dynamic pressure measuring instruments, (3) investigation of the properties of working pressure gages such as those which utilize changes in electrical resistance with pressure, and (4) design and construction of mercury columns to serve as primary standards and for measuring differential pressures of several atmospheres at total pressures up to 30,000 psi.



Left: Controlled-clearance piston gage (at right) used as primary standard of pressure up to 120,000 psi. Instrument on platform (at left) is being calibrated. Near top of standard is fine-bore oil feed line to thrust bearing. Nine 100-lb. dead weights are shown suspended from yoke arrangement. Hydraulic jack at bottom lifts weights on or off suspension. Upper cross arm of yoke is just above jacketing cylinder containing piston-cylinder assembly. Partly concealing jacketing cylinder is motor that rotates piston. Diagram shows the simple dead-weight piston gage for measuring pressures up to several thousand pounds per square inch. Dead weights (left) press on piston which bears on confined liquid below. Dial represents a gage being calibrated against the piston gage. Hand pump at right (turret is oil cup for priming pump) raises pressure until piston and weights are lifted. On closing valve, piston descends slowly. Pressure is calculated from size of dead-weight load and piston cross-sectional area.



Drawing of primary pressure standard, the controlled-clearance piston gage (photo p. 96). Jacketing cylinder, containing thrust bearing piston, and cylinder, is just below the pulley. Loading system consists of steel platters held in chain suspension attached to yoke. Platters are lifted on and off the suspension by hydraulic jack. Load is delivered by thrust bearing to the piston which is rotated independently of the load by means of pulley and motor arrangement (not shown). Yoke suspension rods are electrically insulated from upper crossrail so that electrical tests can show that the weights are supported by the piston and are free of other parts.

Primary Standards

A primary standard of a physical quantity is not calibrated in terms of another instrument measuring the same quantity, but can be referred directly to basic standards of mass, length, and time. Further, the device used in the measurement should be so simple that errors inherent in the instrument can be either eliminated or accurately evaluated.

Two commonly used primary standards of pressure are the mercury column and the dead-weight piston gage. At low pressure the mercury column may be the more accurate of the two, but its range is limited by considerations of convenience. A pressure of 20 psi corresponds approximately to a convenient 40 in. of mercury; but 30,000 psi would require a mercury column about a mile high. The Bureau's program calls for construction of a mercury column 8 m high, capable of extension to 20 m if desired.

The principle of the dead-weight piston gage is most easily seen in the simple type in common use for measurements up to a few thousand pounds per square inch. The metal piston fits closely in a cylindrical opening and is in contact below with a confined fluid. Weights may be placed on top of the piston or be suspended below it by a yoke. A hand pump is used to increase the pressure until it is sufficient to raise the piston and weights free of the lower stop. If friction can be neglected, the pressure is equal to the weight of the piston and its load divided by the cross-sectional area of the piston.

To reduce friction between piston and cylinder, the piston is rotated or oscillated; the weights may move with the piston, or the latter may move independently. At high pressures, it is particularly important that leakage of fluid past the piston be kept small. This is to insure sufficient floating time to establish equilibrium and to make the required observations.

The type of piston gage in use at the Bureau was designed by D. P. Johnson of NBS and D. H. Newhall of Harwood Engineering, Inc.[1] This gage has the novel feature that the clearance between piston and cylinder can be controlled by an independent pressure applied externally to the cylinder. Control of this clearance makes it possible to calculate the pressure under the piston with greatly improved accuracy. The design also permits insertion of different piston-cylinder combinations so that the pressure range can be varied from 0 to 5,000 psi to 0 to 200,000 psi.

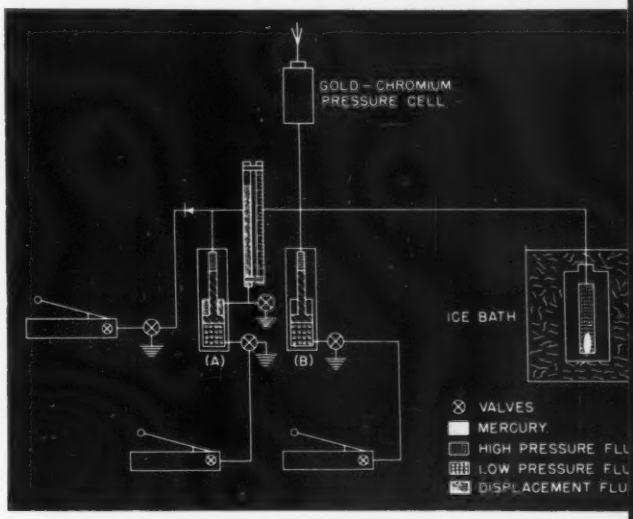
Two such instruments are currently in use at the Bureau for measurements in the ranges 0 to 20,000 psi and 0 to 60,000 psi. The dead weights, made of non-magnetic stainless steel, are held in a chain suspension attached to a yoke. There are nine 100-pound "platters" that may be lifted on or off the suspension by a hydraulic jack at the base, and smaller 5- and 10-pound weights for hand loading.

Since 1952, when they were first constructed, the NBS controlled-clearance piston gages have undergone a succession of refinements. The first problem requiring attention was quick to appear. The design is such that the weights do not rotate with the piston, the vertical weight load being delivered to the rotating piston by a thrust bearing. In the original bearing, the friction made necessary an excessive amount of torque to turn the piston under dead-weight loads above 300 lb. Bureau personnel designed another thrust bearing which floated the dead-weight load on a cushion of high-pressure lubricating oil. This reduced the torque to only a few inch-ounces even for loads of 1,000 lb. Oil under a pressure of 10,000 psi is carried to the bearing through a tube of the kind used for hypodermic needles (0.008 in. bore).

It was soon apparent that improvement was needed also in the roundness and surface finish of the cylinders. Precise measurements on the cylinders were made with a special instrument at the Naval Gun Factory. A 20,000 psi cylinder was finally operated successfully with a tungsten carbide piston. Fall rates of 0.02 in./hr were obtained, which is about 100 times slower than that obtained with commercial piston gages.

Tests in the 60,000 to 120,000 psi range showed the need for an extreme degree of coaxial alinement between piston, cylinder, and certain other parts of the rotating system. An appropriate design modification was worked out jointly by personnel of Harwood Engineering, Inc., and NBS. Also, new cylinders were obtained having the necessary roundness and surface finish. However, it was found that the abrasive material remaining in their bores as a result of the high-speed grinding used in their fabrication resulted in rapid wearing of the piston in use.

Two experiments were started at this point. The first was to have the NBS shop division make a 60,000 psi cylinder from raw material without resorting to high-speed grinding. It proved possible to make a cylinder which was free from residual abrasive material and whose most critical profile fell completely between two circles differing by 7 microinches in radius. A tungsten carbide piston was fabricated by the Van Keuren Co. to fit, and the combination has performed satisfactorily in initial trials. The second experiment was to hone out the 0.079 in., 200,000 psi cylinder to about 0.081 in. to remove residual abrasive, and to have a piston fabricated to fit.



Experimental arrangement for measuring melting pressure of mercury at 0° C (about 110,000 psi). Pressure is measured with gold-chromium resistance wire gage. Afterwards (see figure on p. 101) the gold-chromium gage is calibrated against the controlled-clearance piston gage. Freshly distilled mercury is sealed in polyethylene sack in ice bath. The three lines above the gold-chromium gage lead to an a-c resistance bridge. Two laboratory type intensifiers and three hand pumps are indicated. The displacement fluid, connected to a sight glass, measures the displacement of the intensifier, A. The system is first charged to about 10,000 psi by hand pump (extreme left). Piston of B is then advanced to end of its stroke, raising pressure to about 90,000 psi. Pressure is retained in system between operations by means of the valves. From here on, pressure is raised a little at a time by advancing piston of A until mercury begins to solidify. As the mercury solidifies, it shrinks, so that the apparent volume of the high pressure fluid decreases while the pressure remains constant at the melting pressure. Changes in volume are followed with the sight glass while simultaneous readings are taken on the gold-chromium pressure gage. For details of measuring process, see reference in footnote 1.

Fixed Points

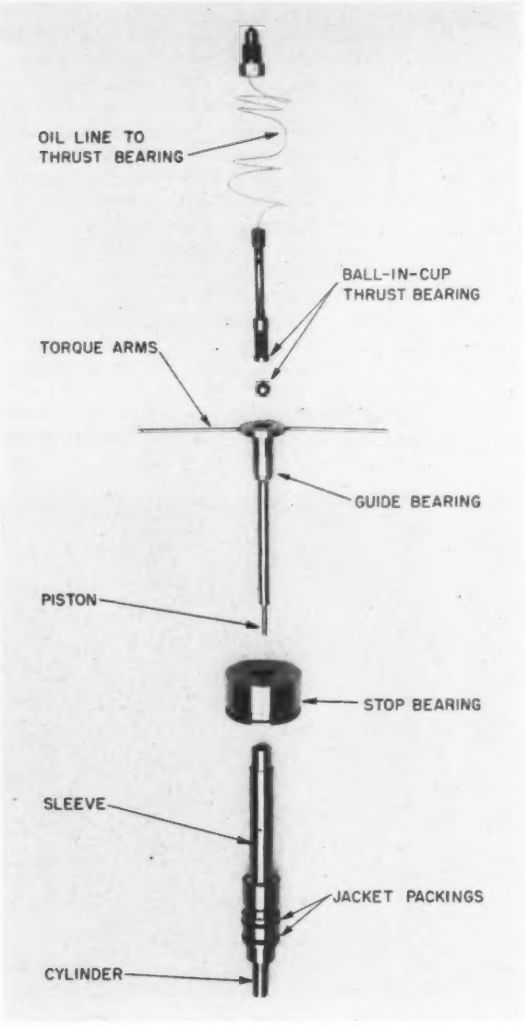
Determination of the sharply defined pressures at which phase transitions occur in various substances serves at least two important purposes. On the one hand, it makes possible a check on long-term changes in the primary standard. On the other, it answers the problem created by the nonportability of primary high pressure standards, since the measurement of an appropriate number of fixed points (once these have been determined with primary instruments) can be used for calibration of working standards.

Some useful high-pressure fixed points are the melting pressure of mercury at 0° C (about 110,000 psi), the melting pressure of water at 30° C (about 150,000 psi), and the transition between crystalline states of bismuth (near 350,000 psi). The boiling pressure of carbon dioxide at 0° C (about 500 psi) has certain advantages over atmospheric pressure as a reference point for high pressure measurements. It is possible that the carbon dioxide point will be the first pressure point for international comparisons. Use of these fixed points requires that the temperature of the material be measured to within 0.003° C for a pressure accuracy of 0.01 percent. The pressures are much less dependent on the temperature in certain of the ice–ice transitions than for the melting and boiling pressures. Thus a measurement of temperature to within 0.05° C will fix the pressure on the ice I–ice III transition near 30,000 psi to about 0.01 percent.

Triple points, which are unique in both temperature and pressure, seem to have advantages over transitions in which pressure depends on temperature. A particularly valuable set of triple points is that associated with water at about 30,000, 50,000, and 90,000 psi. These would give, in a single experimental setup, a three-point calibration covering a range of considerable industrial interest.

Largely to test the possibilities of the controlled clearance piston gage, and to acquire experience with this type of experiment, a determination of the melting pressure of mercury at 0° C was made jointly by the Foxboro Co., Harwood Engineering, Inc., and the Bureau.[1] Melting pressure readings were first taken with a gold-chromium wire pressure cell which was afterwards calibrated with the piston gage. The value obtained agreed with Bridgman's result (published in 1912) to within 0.5 percent.

Exploratory experiments have also been conducted in the region of the ice I–ice III liquid triple point (near 30,000 psi) and experimentation has been per-



Exploded view of piston and cylinder assembly in primary standard of high pressure. A dead-weight load (not shown) is transmitted through ball-in-cup thrust bearing to piston. Piston fits into cylinder (shown partially inserted into its sleeve) and comes in contact with pressure fluid. Piston and guide bearing are rotated by motor arrangement (not shown) independently of the dead-weight load. This reduces friction between piston and cylinder. However, friction now appears at the thrust bearing, and this is reduced by floating the thrust bearing (and its dead-weight load) on a cushion of lubricating oil at 10,000 psi. The oil is brought in through fine-bore oil feed and passes down through center of thrust bearing. This reduces frictional torque to a few inch-ounces.

formed with ice VI and liquid in two-phase thermal equilibrium at about 140,000 psi. It is planned to investigate the other fixed pressure points below 60,000 psi.

In order to carry out these investigations, accessories capable of generating and containing, without leakage, pressures up to 200,000 psi (and ultimately, 350,000 psi) are needed. Some commercial components for pressures of the order of 200,000 psi are available. However, the requirement of complete freedom from leakage in the present work has necessitated the modification of a large proportion of the commerically obtained equipment.

To illustrate this point, an experiment on the phase transition between water and ice VI may become meaningless if a leak exists of 1 or 2 drops per week at 150,000 psi. Such a leak occurred in an early trial and was traced to the moving seal of the intensifier [2] in use. Other intensifiers were checked and exhibited comparable leakage. After much experimentation, the packing configuration was redesigned and the packing material changed so that leakage was no longer detectable. At the same time, ease of assembly and disassembly was improved and packing friction was reduced.

Resistance Wire Gages

One of the most convenient and universally used methods of measuring high pressures depends on the fact that the electrical conductivity of most substances changes as a function of the pressure applied to the conductor. Hence, by inserting a previously calibrated coil in a pressure vessel and determining its resistance, a measure of the interior pressure is obtained.

Unfortunately, most substances have a temperature coefficient of resistance as well as a pressure coefficient. To be certain that the two effects are not confused, it is customary to select a substance with a negligibly small temperature coefficient at some convenient temperature. Then, by operating at that temperature, changes in resistance can be assigned to the pressure surrounding the conductor.

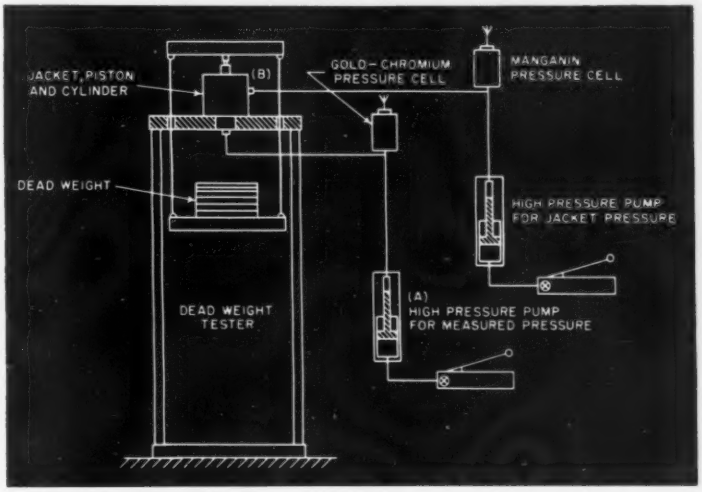
Working gages of this type commonly employ alloys of manganin or gold chromium, since these materials have sufficiently large pressure coefficients of resistance, while their resistance is relatively insensitive to temperature changes in the ambient range. In particular, manganin has been used for pressures from 20,000 to at least 400,000 psi. The resistance is usually measured with a bridge circuit.

Several features of manganin gages have been investigated by previous experimenters. These studies indicated that additional work was called for, particularly on the method of mounting and supporting the wire in the pressure fluid. The evidence indicated that reduction of mechanical strain in the resistance wire would result in greater stability and more nearly linear relation between coil resistance and pressure. This is strikingly similar to the problem of mounting and supporting the platinum wire in resistance thermometry. There were some differences of opinion on the most desirable techniques for pressure and temperature seasoning of the completed gage, and some questions to be resolved regarding the influence of aging and the effect of various bridge techniques on accuracy.

Before any of these items were investigated, a closure plug was devised through which four leads (two from each terminal of the resistance coil) could be brought out from the pressure vessel. Commercially available gages are ordinarily constructed so that one end of the wire coil is grounded to the interior of the vessel while the other end is brought outside through an insulated lead. In observing the resistance changes of the wire in such a gage, parts of the electrical lead wires as well as parts of the other equipment must be included in the electrical circuit of the bridge. Such a system has the disadvantage that changes in the electrical resistance of these external elements may well mask small changes in the resistance of the pressure coil itself.

The advantages of a four-wire connection to the coil have been pointed out in the literature on resistance thermometers. In addition to eliminating the sources of error indicated above, it makes possible the determination of the resistance of the leads themselves. The device finally adopted had four leads in the space previously required for one lead in commercial gages and the insulation resistance was about 1,000 megohms per lead.[3]

Several of these closure plugs were constructed and various types of resistance wire gages attached. A study of manganin wire coils led to the devising of a configuration that gives substantial improvement in the resistance stability and the linearity of the pressure-resistance characteristic over commercially available types. Data were taken on the effect of heat treatment on gold chromium, and its pressure coefficient was determined to 20,000 psi. Utilizing the ice VI-liquid transition line as a reference pressure, several types of manganin wire gages were compared. Further work along these lines is continuing, but much more will be possible when a primary standard of pressure to 200,000 psi is attained.



Experimental arrangement for calibrating gold-chromium gage against NBS controlled-clearance piston gage (dead-weight tester), performed as part of determination of melting pressure of mercury at 0° C (see figure on p. 99). The manganin pressure cell (resistance wire gage) was used for determining the constancy of the independent pressure for adjusting the clearance between piston and cylinder within B. Pressure generated by hand pump A is balanced by dead weights. The pressure is calculated from size of piston and the dead weights. Readings of the gold-chromium cell are then compared with calculated values of the pressure.

Dynamic Pressure Measurements

In preparation for the work on the measurement of rapidly changing pressures, a detailed bibliography[4] was compiled and a survey made of existing methods and instrumentation. For calibration purposes, one would desire a pressure pulse of accurately known amplitude and time characteristics (e. g., rise time and duration). A shock wave is useful at low pressures, but is less accurate at high pressures because of lack of knowledge of the equation of state.

Devices are in use which generate a step function in pressure (usually negative-going, i. e., a sudden decrease in pressure) whose amplitude can be evaluated but whose time characteristics are unknown. Other devices generate positive pressure pulses whose time and amplitude characteristics cannot be separated except partially and with the utmost difficulty. Without such separation, the peak pressures are unknown.

The pressure measurements laboratory has started development of a quick-opening valve to be placed between a large volume accumulator and a small volume containing a dynamic gage under test. A positive-going pulse will be produced whose initial and final pressures can be accurately determined. The peak amplitude of the pulse will be from 50,000 to 100,000 psi.

Studies, thus far theoretical only, are also being made of the falling-weight type of pulse generator. In these devices, a weight falls on a piston which, in turn, communicates a pressure pulse to a confined fluid.

Most of the types of investigation described above will be continued. The principal aims are, of course, to extend the range of primary standards and to improve the accuracy of fundamental measurements. Apparatus to develop higher pressures is being constructed and will be placed in operation. One of its

principal uses will be the determination of fixed points. Increased accuracy will be sought by intercomparison of gages in the region of overlap and by refinements in the design of the piston gages.

[1] *See* The piston gage as a precise measuring instrument, *by D. P. Johnson and D. H. Newhall, ASME Trans.* **75,** *301 (1953).*

[2] *An intensifier is essentially a piston whose cross section is large at one end and small at the other. A low pressure distributed over the large area will balance a high pressure over the small area (see for example, B in photo on p. 99).*

[3] Insulating seal for high pressure equipment, *NBS Tech. News Bull.* **39,** *71 (May 1955). For further technical details on improvements in high pressure accessories, see also* Impregnated Teflon as a packing material at 150,000 pounds per square inch, *by H. A. Bowman, J. L. Cross, D. P. Johnson, and J. S. Ives, Rev. Sci. Instr. (in press);* A versatile closure for high pressure vessels utilizing O-rings for the initial seal, *by D. P. Johnson, H. A. Bowman, J. L. Cross, J. D. Hill, and J. S. Ives, J. Instrument Soc. Amer. (in press).*

[4] Bibliography and index on dynamic pressure measurement, *by W. G. Brombacher and T. W. Lashof, NBS Circular 558 (1955), available from Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., for 75 cents.*

Meetings on Radiation Units and Protection

IMPORTANT decisions relating to the measurement and safe use of radiations were announced at the triennial meetings of the International Commission on Radiological Units and the International Commission on Radiological Protection, both of which were held April 2–11, 1956, in Geneva, Switzerland.[1] In a move to achieve greater international uniformity of X-ray measurements, the ICRU initiated a project in which basic equipment, to be developed by the Bureau, will be loaned to countries that lack primary standards of their own. The principal outcome of ICRP deliberations, on the other hand, was a revised set of recommendations for permissible levels of ionizing radiation to which human beings may be exposed. Another highlight of the ICRU meetings was a discussion of problems raised in translating measurements made in roentgens to the newer unit of absorbed dose, the *rad*.

Units Commission

The ICRU has been in active existence since it was established by the first International Congress of Radiology in 1925. Its major objective is the establishment of units of radiation dosage for use in medicine and biology, and in this field it has set the world pattern for over 30 years. At the same time, it deals with special problems of radiation measurement in both clinical and biological applications, and establishes the necessary nomenclature and descriptive procedures in regard to radiation doses.

Problems facing the ICRU have become increasingly complex as radiation energies have moved to higher and higher values, and as other ionizing radiations requiring measurement, such as neutrons, have been introduced. An important step in advancing the common base for all radiation measurements was taken in 1953 with the introduction of an energy unit of measurement called the *rad*. The rad, equal to 100 ergs per gram of irradiated matter, for the first time expresses radiation dose directly in terms of basic physical units. Determination of dose in terms of the older unit, the roentgen, involves only ionization measurements, and the transition to the techniques of energy measurement has been difficult. Much of the recent meeting was therefore devoted to developing background material needed to make energy measurements more practical under clinical and experimental conditions. The forthcoming report of the Commission will contain not only this extensive body of material, but also the physical and numerical factors needed to convert ionization measurements made with conventional instruments to energy measurements applicable to radiation absorption in tissue.

It was brought out at the ICRU meeting that few countries have primary standards of X-ray dosage with the requisite range and accuracy. Though in the recent or distant past, intercomparisons of primary standards have been made between the United States, Great Britain, Sweden, France, Germany, and Canada, a great many other countries that use X-rays and gamma rays from radioactive nuclides are without the benefits of central national laboratories. To improve this situation, the Commission recommended that a secondary X-ray standard be developed and constructed which can be loaned to other countries for the calibration of the working standards which in turn are used to control radiation measurements in their hospitals and research institutions.

The National Bureau of Standards was asked to undertake this program and has agreed to do so. The plan is for the Bureau to construct a suitable cavity ionization chamber which can be calibrated over a wide energy range against the NBS primary standards. To control the measurements of the ionization chamber, a standard capacitor will also be provided. The Bureau will also supply a standard diaphragm to be used in intercomparing free-air standards in those laboratories having them.

Protection Commission

Established in 1928, the ICRP has had the responsibility for setting the working levels of ionization radiation to which all persons may safely be exposed. When the Commission's work began, there was little thought that its findings and recommendations would play so important a part in the international picture of radiation use. It was fortunate, indeed, that its first recommendations on permissible exposure, made in 1934, were able to provide the guide lines for protection.

Work of the ICRP has been closely paralleled by that of the U. S. National Committee on Radiation Protection (NCRP), which was formed in 1929. The two groups have substantial overlapping of membership on their subcommittees which, in turn, are formed along similar lines. In fact, a part of the present International Recommendations on Radiological Protection follows the pattern set by the NCRP.

The 1934 recommendations on permissible exposures were based mainly on the possible harm to the individual working with X-rays. Virtually no thought was given to possible genetic effects. However, as a result of the intensified study of this question during the Manhattan District days, and new evidence which indicated the possibility of both genetic effects and long-range effects on the individual, a review of these questions was made by both the national and international commissions. In 1948, the NCRP recommended that the permissible levels of radiation exposure be reduced by a factor of about two. Thus the permissible exposure of 0.1 roentgen per day was lowered to 0.3 roentgens per week. The same basic figure was subsequently adopted by the ICRP in 1950.

Since 1950, it has become increasingly clear that larger fractions of the population will be exposed to radiation from both medical and atomic energy sources. It therefore became paramount to reassess the whole protection problem, and to take into account the newer evidence on possible long-range genetic effects and possible shortening of individual life-span due to radiation exposure. The ICRP took up these problems at Stockholm in 1952, and its latest recommendations again provide for a lowering of the permissible exposure.

It is proposed that a lowering be achieved without changing the basic level of 0.3 roentgen per week. If this maximum level were maintained indefinitely, it would mean an exposure of about 15 roentgens a year, or between 400 and 600 roentgens per working lifetime. The Commission has agreed that exposure of a substantial fraction of the population to this much radiation is undesirable. Accordingly, while adhering to the permissible exposure of 0.3 roentgen per week, the latest recommendations of the ICRP state that it is inadvisable for an individual to receive more than 50 roentgens up to his age of 30, 100 roentgens up to age 40, and 200 roentgens up to age 60. This means that individuals who are exposed to radiation at the maximum level will be allowed to work only one-third of the time. In effect, the normal daily working level is reduced by a factor of about 3.

This will not be as difficult to carry out as might at first appear, since most of the large atomic energy and other radiation establishments in this country are already operating at exposure levels considerably below even the new reduced amount. It is rare for workers, even today, to be exposed to more than about one-fifth of the present permissible amount.

The new recommendations will, however, introduce a penalty on those installations that insist upon exposing their workers to the maximum permissible weekly amount. Under the new rules, such workers may be exposed to this level for only one-third of their working time, the penalty thus taking the form of intermittent and hence uneconomic use of personnel. The inducement will therefore be strong for such installations to improve their protection facilities to the point where the maximum radiation exposure will not exceed the newly recommended average levels.

NBS Participation in the Meetings

The participation of the National Bureau of Standards in the international protection program dates from 1928, the year in which the ICRP was formed. Since then, the Bureau's radiation research program has grown steadily in variety and scope. It now includes the gathering of basic radiation data with the 50-million-volt betatron and 180-million-volt synchrotron, theoretical studies on radiation penetration and diffusion, development of instruments for detecting and measuring radiation, and publication of handbooks on methods of safe handling of X-rays and radioactive nuclides. An accelerated program also has been started on the study of protection against neutrons.

The Bureau's participation together with other representatives from the U. S. in the work of the two international commissions was markedly increased as a result of the recent meetings. In the case of the Bureau, this appears not only in its preparation of a portable X-ray standard, but in the parts assigned to the following NBS staff members in the work of the commissions. L. S. Taylor, chief of the NBS division of atomic and radiation physics, was renominated for an additional 3-year term as chairman of the ICRU and as a member of the ICRP. H. O. Wykoff, chief of the radiation physics laboratory, continues as member of the ICRP committee on protection against X-rays generated by voltages up to 3 million volts. He has for several years been chairman of the corresponding subcommittee of the NCRP. Dr. Wykoff was also nominated as a member of the ICRU and chairman of its committee on standards and measurements of radiological exposure.

W. B. Mann, chief of the radioactivity laboratory, was nominated cochairman of the ICRU committee on standards and measurement of radioactivity. H. F. Attix, member of the X-ray laboratory staff, was named to the ICRU committee on standards and measurement of absorbed dose. Mrs. S. Raskin, staff member of the radiation physics laboratory, attended the meetings as technical secretary to the chairman. H. W. Koch, chief of the betatron laboratory, continues on the ICRP committee on protection against X-rays above 3 million volts, beta rays, gamma rays, and heavy particles, including neutrons and protons. S. W. Smith, chief of the radiological equipment laboratory, was nominated as a new member of the ICRU committee on standards and methods of measurements of characteristic data of radiological equipment and materials used in diagnostic and therapeutic radiology.

[1] *The reports of the two commissions are expected to be published in the late fall of 1956. The ICRU report will appear in the form of an NBS Handbook, and the ICRP report will be published as a supplement to the British Journal of Radiology.*

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NATIONAL BUREAU OF STANDARDS
A. V. ASTIN, *Director*

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Technical News Bulletin, volume **40,** No. 6, June 1956. 10 cents. Annual subscription $1.00.

Basic Radio Propagation Predictions for September 1956. Three months in advance. CRPL 142. Issued June 1956. 10 cents. Annual subscription $1.00.

Research Papers

Journal of Research, volume **56,** *No. 6, June 1956. Single copies of the Journal vary in price. Single copies of Research Papers appearing in the Journal are not available for sale. The Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., will reprint 100 or more copies of a Research Paper. Requests for the purchase price should be mailed promptly to that office.*

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